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THE

# MINERALOGICAL MAGAZINE

AND

## Journal of

# The Mineralogical Society

(*INSTITUTED FEBRUARY 3, 1876.*)

WITH A SEPARATELY-PAGED APPENDIX OF

# MINERALOGICAL ABSTRACTS

EDITED BY L. J. SPENCER, F.R.S.

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# MINERALOGICAL SOCIETY

## Officers and Council for 1929–30.

*PRESIDENT.*

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H. Collingridge, B.Sc., F.G.S.
Prof. C. G. Cullis, D.Sc., F.G.S.
G. McDonald Davies, M.Sc., F.G.S.
Henry Dewey, F.G.S.
Prof. W. G. Fearnsides, M.A., F.G.S.
Prof. Harold Hilton, M.A., D.Sc.
Prof. Arthur Holmes, D.Sc., F.G.S.
W. F. P. McLintock, D.Sc., F.G.S.
Miss M. W. Porter, B.Sc.

*LIBRARIAN.*

Miss J. M. Sweet, B.Sc., *British Museum of Natural History, South Kensington, London, S.W.* 7 (to which address all publications intended for the Library of the Society should be forwarded).

*Bankers.*—Messrs. Coutts & Co., 15 *Lombard Street, London, E.C.* 3.

# PROCEEDINGS
OF THE
# MINERALOGICAL SOCIETY

## EXCERPT MINUTES OF COUNCIL MEETING.

*Held in the Apartments of the Geological Society, Burlington House, London, W., January* 15, 1929, *at* 4 *p.m.*

Dr. G. T. Prior, F.R.S., President, in the Chair.

The death of Mr. Franklin White on October 28 was announced.

Messrs. Victor Ambrose Eyles, William Quarrier Kennedy, Archibald Gordon MacGregor, Murray Macgregor, James Ernest Richey, Max Hutchinson Hey, and Professor Leonhard Weber were provisionally elected Ordinary Members of the Society.

The Treasurer presented the audited accounts and balance-sheet for the year ending December 31, 1928, which, were approved.

The Treasurer reported on the meeting called by the British Association in January to consider the position of scientific societies in regard to income tax.

The Librarian made a report on the state of the Library of the Society and the necessity of moving it from the Mineralogical Schools at Cambridge as the room it occupied was required by the department. The following were nominated to serve on a committee 'to consider the future housing of the Library, and to report in March': the Librarian, the Secretary, the Editor, the Treasurer, Dr. G. F. Herbert Smith, and Prof. Harold Hilton.

## GENERAL MEETING.

*Held in the Apartments of the Geological Society, Burlington House, London, W., January* 15, 1929, *at* 5.30 *p.m.*

Dr. G. T. Prior, F.R.S., President, in the Chair.

Thirty-one Members and five Visitors were present.

The elections of Messrs. V. A. Eyles, W. Q. Kennedy, A. G. MacGregor, M. Macgregor, J. E. Richey, M. H. Hey, and Prof. L. Weber as Ordinary Members of the Society were confirmed.

The following papers were read :—

1. The tholeiite dikes of the north of England : by Prof. Arthur Holmes and Dr. H. F. Harwood (p. 1).

2. On the occurrence of gold at Hope's Nose, Torquay, Devonshire : by Mr. Arthur Russell (p. 159).

A paper on the crystallography of some organic compounds, by Mr. H. E. Buckley, was taken as read.

Mr. C. S. Hitchen exhibited a fine specimen from Boltsburn mine, Weardale, Co. Durham, illustrating a sequence of crystalline growths —galena, chalybite, purple fluorite, quartz, green fluorite, calcite.

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## EXCERPT MINUTES OF COUNCIL MEETING.

*Held in the Apartments of the Geological Society, Burlington House, London, W., March* 19, 1929, *at* 4.30 *p.m.*

Dr. G. T. Prior, F.R.S., President, in the Chair.

The death of Mr. Bristow J. Tully on February 13 was announced.

Messrs. John Desmond Bernal, Sidney Ewart Hollingworth, Horace Woollaston Monckton, Edward James Wayland, Alfred Kingsley Wells, and William Dixon West were provisionally elected Ordinary Members of the Society.

The Treasurer reported that he had had photographic reproductions made, at his own expense, of pp. 261–284 of No. 20 of the Magazine, as it was found that certain copies in libraries and in the remaining stock were wanting these sheets which were issued loose to replace pp. 261–270. He proposed to present copies to all who asked for them. It was agreed to accept this offer with thanks, and to put an advertisement in the next number of the Magazine.

A report was received from the committee appointed to consider the housing of the Society's Library and also a letter from the Trustees of the British Museum. It was decided to accept the offer of the Trustees to keep the Library temporarily at the British Museum of Natural History on condition that it be kept separate from the Library of the Mineral Department and subject to the proviso that the Trustees accept no responsibility for any loss or damage to the books while housed in the Museum. The Secretary was instructed to thank the Trustees.

The resignation of Prof. A. Hutchinson from the office of Librarian, consequent on the removal of the Library from Cambridge, was accepted, and a vote of thanks to him was passed. Miss J. M. Sweet was elected as Librarian.

## GENERAL MEETING.

*Held in the Apartments of the Geological Society, Burlington House, London, W., March* 19, 1929, *at* 5.30 *p.m.*

Dr. G. T. Prior, F.R.S., President, in the Chair.

Twenty Members and five Visitors were present.

The elections of Messrs. J. D. Bernal, S. E. Hollingworth, H. W. Monckton, E. J. Wayland, A. K. Wells, and W. D. West as Ordinary Members of the Society were confirmed.

The following papers were read :—

1. The inclusions in the apatites of some igneous rocks: by Dr. A. W. Groves and Mr. A. E. Mourant (p. 92).

2. Calc-gneisses and cordierite-sillimanite-gneisses of Coimbatore, Madras Presidency, and of similar occurrences in India: by Mr. L. A. Narayana Iyer (p. 121).

3. A relation between the density and refractive index of silicate glasses, with application to the determination of imitation gem-stones: by Mr. F. A. Bannister (p. 136).

4. The crystallization of potash-alum: by Mr. H. E. Buckley.

Mr. A. F. Hallimond exhibited on behalf of H.M. Geological Survey a simple form of projection microscope by E. Leitz, and showed thin sections of lapis-lazuli and other minerals therewith. Prof. W. T. Gordon exhibited fine crystals of apatite from Canada.

## EXCERPT MINUTES OF COUNCIL MEETING.

*Held in the Apartments of the Geological Society, Burlington House, London, W., June* 11, 1929, *at* 4.15 *p.m.*

Dr. G. T. Prior, F.R.S., President, in the Chair.

Sir Douglas Mawson was provisionally elected an Ordinary Member of the Society.

The resignation of Mr. H. Baker was accepted.

The Treasurer reported that the Society's claim for exemption of income tax had been granted.

Prof. Hutchinson reported that the removal of the Society's Library from Cambridge was carried out on June 10, and Dr. Spencer reported that the books were now housed in the Mineral Department of the British Museum of Natural History. The rules for the Library were discussed and agreed to. It was decided to print 500 copies and circulate to all members; also to procure a rubber stamp for marking all the Society's books.

The following changes in the list of Officers and Council were proposed. Dr. G. F. Herbert Smith to be a Vice-President in place of Dr. J. W. Evans (who would remain as Foreign Secretary only). To be asked to stand for election as Ordinary Members of Council: Dr. A. Brammall and Miss M. W. Porter, as former members; Prof. W. G. Fearnsides and G. M. Davies as new members. The four senior Ordinary Members due to retire were Prof. H. L. Bowman, Prof. W. T. Gordon, Dr. H. F. Harwood, and Dr. G. F. Herbert Smith.

It was decided to hold meetings in 1930 on the following dates: Tuesdays, January 14, March 18, June 3, November 4.

Attention was drawn to the fact that Mr. S. Henson and Prof. H. Louis would complete fifty years of membership in June and October respectively. The President agreed to send to them letters of congratulation.

A letter was received from the University of Cape Town, and it was decided to ask Prof. S. J. Shand of Stellenbosch University to act as the Society's delegate at the celebration of the Centenary of the South African College on October 5.

## GENERAL MEETING.

*Held in the Apartments of the Geological Society, Burlington House, London, W., June* 11, 1929, *at* 5.30 *p.m.*

Dr. G. T. Prior, F.R.S., President, in the Chair.

Twenty-three Members and five Visitors were present.

The election of Sir Douglas Mawson as an Ordinary Member of the Society was confirmed.

The following papers were read:—

1. Bismutotantalite, a new mineral, from Uganda: by Mr. E. J. Wayland and Dr. L. J. Spencer (p. 185).

2. On a partially fused quartz-felspar-rock and on glomero-granular texture: by Dr. L. Hawkes (p. 163).

3. The occurrence of a mineral hitherto unrecognized in the phonolites of Dunedin, New Zealand : by Dr. P. Marshall (p. 174).

4. The meteoric stone of Lake Brown, Western Australia : by Dr. G. T. Prior (p. 155).

Dr. L. J. Spencer exhibited on behalf of the authors, Mr. I. de Finály and Dr. S. Koch, Fülöppite, a new Hungarian mineral of the plagionite-semseyite group (p. 179); and also klebelsbergite from Felsőbánya, recently described by Dr. V. Zsivny, who was present at the meeting.

## EXCERPT MINUTES OF COUNCIL MEETING.

*Held in the Apartments of the Geological Society, Burlington House, London, W., November* 5, 1929, *at* 4 *p.m.*

Dr. G. T. Prior, F.R.S., President, in the Chair.

The death of Mr. J. Lainson Wills on February 28 was announced.

Mr. Percy Blight, Mr. George Wynter Gray, Mr. Ben Lightfoot, Dr. Louis Taylor Nel, Prof. Alexander Hamilton Phillips, Prof. Edward Sampson, and Dr. Marcel Jean Louis Solignac were provisionally elected Ordinary Members of the Society.

The Editor read a letter from Dr. Károly Zimányi of the Hungarian National Museum, Budapest, saying that owing to failing eyesight he could not continue abstracting the Hungarian literature for Mineralogical Abstracts, and that Dr. V. Zsivny would be prepared to take his place. The Editor was asked to write a letter of thanks and sympathy to Dr. Zimányi.

The Librarian reported that the Library of the Society arrived at the Natural History Museum in June, since when it has been rearranged and the periodicals catalogued. A list of the more important periodicals has been printed, together with the rules, and copies have been sent to all members. A catalogue of the separata is in course of preparation.

Mr. T. Crook and Mr. A. J. Bull were appointed auditors of the accounts for the year ending December 31, 1929.

The Annual Report of the Council, submitted by the Secretary, was read and approved.

A letter was read from the Federal Council for Chemistry, and it was decided that the Society should cease to be a constituent member of that organization. It was decided to forward a donation of £5 towards the funds of the Federal Council.

## GENERAL (ANNIVERSARY) MEETING.

*Held in the Apartments of the Geological Society, Burlington House, London, W., November* 5, 1929, *at* 5.30 *p.m.*

Dr. G. T. Prior, F.R.S., President, in the Chair.

Twenty-five Members and eight Visitors were present.

The President nominated Mr. A. F. Hallimond and Mr. C. S. Hitchen to act as scrutineers of the voting-papers for the election of Officers and Council. The scrutineers reported that seventy-seven voting-papers had been returned to the Secretary, and that the list as nominated by the Council was approved, namely :—

*President.* Dr. G. T. Prior, M.A., D.Sc., F.R.S.

*Vice-Presidents.* Sir John S. Flett, K.B.E., M.A., LL.D., D.Sc., F.R.S.

Dr. G. F. Herbert Smith, M.A., D.Sc., F.G.S., F.R.A.S.

*Treasurer.* F. N. Ashcroft, M.A., F.G.S., F.C.S.

*General Secretary.* W. Campbell Smith, M.C., T.D., M.A., F.G.S.

*Foreign Secretary.* Dr. J. W. Evans, C.B.E., D.Sc., LL.B., F.R.S.

*Editor of the Journal.* Dr. L. J. Spencer, M.A., Sc.D., F.R.S.

*Ordinary Members of Council.*

A. J. Bull, M.Sc., F.Inst.P., F.G.S.
Prof. C. G. Cullis, D.Sc., F.G.S.
Prof. Harold Hilton, M.A., D.Sc.
Dr. W. P. F. McLintock, D.Sc., F.G.S.
Colonel N. T. Belaiew, C.B., F.C.S.
Harvey Collingridge, B.Sc., F.G.S.
Henry Dewey, F.G.S.
Prof. Arthur Holmes, D.Sc., F.G.S.
Dr. A. Brammall, Ph.D., M.Sc., F.G.S.
G. MacDonald Davies, M.Sc., F.G.S.
Prof. W. G. Fearnsides, M.A., F.G.S.
Miss W. M. Porter, B.Sc.

The elections of Mr. P. Blight, Mr. G. W. Gray, Mr. B. Lightfoot, Dr. L. T. Nel, Prof. A. H. Phillips, Prof. E. Sampson, and Dr. M. J. L. Solignac as Ordinary Members of the Society were confirmed.

The General Secretary then read the following

### Annual Report of Council.

During the session 1928–9 four ordinary meetings have been held, by kind permission, in the apartments of the Geological Society, Burlington House,

London, W., at which fourteen papers were read. There were exhibits of specimens and apparatus at each of the four meetings.

Four numbers of the Journal of the Society (nos. 123–126) have been issued. No. 123 consists of indexes to vol. 21 of the Magazine and vol. 3 of the Abstracts. In these indexes, which have been prepared by the Editor, there are about 15,000 entries. Nos. 124–126 contain twelve papers occupying 162 pages with six plates, and 444 abstracts occupying 144 pages.

The balance-sheet for the year ending December 31, 1928, showed assets (exclusive of the Library and stock of the publications) £1,986 0*s.* 8*d.*, with liabilities nil. The value of the stock invested in the names of the Trustees of the Society was on December 31, 1928, £1,708 8*s.* 6*d.*, equivalent to £34 3*s.* 4½*d.* for each life-member.

In view of the uncertainty which had arisen as to the position of scientific societies in the matter of liability for income tax (on income derived from invested funds), the Treasurer raised the matter with the Inland Revenue authorities and prepared a statement showing the objects and scientific activities of the Society and the application of its funds. This statement was submitted to the authorities concerned, was accepted, and the continuance of exemption from tax was granted.

Seventeen new members have been elected, two ordinary members have resigned, and two have died, leaving the total membership on October 31 at 221 including eleven honorary members. The two members whose deaths have to be reported are Mr. Joseph Lainson Wills and Mr. Bristow J. Tully. Mr. Lainson Wills was the sole surviving original member of the Society; for many years he had resided in New York City, where he died on February 28, 1929.

The Society's Library, which since 1890 has been housed in the Mineralogical Museum of Cambridge University, has been moved during the year to the Mineral Department of the British Museum of Natural History, where temporary accommodation for it has been generously provided by the Trustees. The Society owes a debt of gratitude to the Department of Mineralogy at Cambridge for having provided a home for the Library for many years, and to Professor Hutchinson for the very useful work which he did while Librarian. Miss J. M. Sweet has been appointed Librarian. A printed list of the most important serials in the Library has been issued, and the books are now available for use by the members of the Society on week-days between the hours of 10 a.m. and 4.30 p.m.

The President has continued to represent the Society on the Federal Council for Chemistry, and Dr. G. F. Herbert Smith on the Miscellaneous Minerals Committee of the Mineral Resources Department of the Imperial Institute. Professor S. J. Shand, of Stellenbosch University, acted as the Society's delegate at the celebration of the Centenary of the South African College (University of Cape Town) on October 5, and on October 17 Mr. James Broadhead represented the Society at the Centenary celebrations of the Natural History Society of Northumberland, Durham, and Newcastle-upon-Tyne.

Miss G. L. Elles proposed, and Mr. M. H. Hey seconded, a vote of thanks to the Geological Society for the use of their rooms, which was carried unanimously. [*continued on p. xlviii.*]

# MINERALOGICAL

## ABSTRACT OF RECEIPTS AND PAYMENTS

| Receipts. | £ s. d. | £ s. d. | GENERAL PUR- £ s. d. |
|---|---|---|---|
| By Balances brought forward from 1928— | | | |
| 1. At Bankers: | | | |
| (*a*) Current Account | 7 11 6 | | |
| (*b*) Deposit Account | 125 0 0 | | |
| 2. In Office | 0 8 10 | | |
| | | 133 0 4 | |
| Entrance Fees | | 19 19 0 | |
| Annual Subscriptions— | | | |
| 1. Current year | 151 16 0 | | |
| 2. Arrears | 5 6 1[1] | | |
| 3. Advance | 7 9 1[1] | | |
| | | 164 11 2 | |
| Composition Fees | | — | |
| Sale of Publications— | | | |
| 1. By Publishers, April 1, 1928–March 31, 1929. Subscription Payments £178 0*s.* 0*d.*, and other sales £105 0*s.* 6*d.*, less trade discount and commission £79 10*s.* 2*d.*, and distribution charges £8 11*s.* 2*d.* | 194 19 2 | | |
| 2. By Custodian of Stock, 1929. £105 2*s.* 3*d.*, (including profit on sale of second-hand set) less cost of out-of-print numbers purchased £1 10*s.* 0*d.*, and distribution charges £2 8*s.* 9*d.* | 101 3 6 | | |
| | | 296 2 8 | |
| Advertisement Fees £19 1*s.* 3*d.*, less commission £3 16*s.* 3*d.* | | 15 5 0 | |
| Interest on Investments as received— | | | |
| 1. £1,580 5% War Loan 1929–47 Inscribed Stock | 76 10 0 | | |
| 2. £105 4% Consolidated Loan 1957 Inscribed Stock | 4 4 0 | | |
| 3. £50 4% Funding Loan 1960–90 Inscribed Stock | 2 0 0 | | |
| | | 82 14 0 | |
| Deposit Interest | | 8 9 2 | |
| Small Receipts | | 0 1 9 | |
| In trust for a Member | | 1 14 2 | |
| | | £721 17 3 | |

[1] Including part payments.

# SOCIETY

## FOR THE YEAR ENDING DECEMBER 31, 1929

POSES ACCOUNT.

| Payments. | £ s. d. | £ s. d. |
|---|---|---|
| To Printing and distributing the Mineralogical Magazine Nos. 124–127 inclusive (Oxford University Press)— | | |
| 1. Printing. . . . . | 297 2 0 | |
| 2. Illustrations . . . . . | 42 12 0 | |
| 3. Authors' Separate Copies . . . . | 27 9 6 | |
| 4. Distribution Charges . . . . . | 13 14 0 | |
| 5. Printed postal wrappers (renewal of stock) . | 2 1 6 | |
| | | 382 19 0 |
| Printing and distributing notices of Meetings and other annual miscellaneous printing . . | . . . | 16 0 0 |
| Miscellaneous Printing, &c. (not annual)— | | |
| 1. Bye-laws and List of Members . . . | 1 17 6 | |
| 2. Banker's orders . . . . . | 1 1 0 | |
| 3. Treasurer's Compliments slips . . . | 0 18 6 | |
| 4. Income Tax Memorandum (typing) . . | 1 10 0 | |
| | | 5 7 0 |
| Expenses at Meetings, 1929— | | |
| 1. Operator of lantern . . . . . | 2 2 0 | |
| 2. Porter . . . . . | 1 0 0 | |
| | | 3 2 0 |
| Care of Stock of Publications, 1929 (J. Mugford) . | . . . | 1 1 0 |
| Editor's Honorarium, 1929 . . . . . | . . . | 50 0 0 |
| Postage— | | |
| 1. Hon. Secretary . . . . . | 1 1 3 | |
| 2. Editor . . . . . | 1 8 1 | |
| 3. Hon. Treasurer (not charged) . . . | — | |
| | | 2 9 4 |
| Bank charges and other small items . . . . | . . . | 0 13 7 |
| Donations— | | |
| 1. Federal Council for Chemistry . . . | 5 0 0 | |
| 2. Cesàro Portrait Fund . . . . . | 2 2 0 | |
| | | 7 2 0 |
| Investments, purchase of £50 5% War Loan, 1929–47 Inscribed Stock, commission and stamp . | . . . | 50 9 11 |
| Transferred to Library Fund Account . . . | . . . | 22 0 0 |
| Balance, December 31, 1929— | | |
| 1. At Bankers: | | |
| (*a*) Current Account . . . . . | 10 3 8 | |
| (*b*) Deposit Account . . . . . | 170 0 0 | |
| 2. In Office . . . . . | 0 9 9 | |
| | | 180 13 5 |
| | | £721 17 3 |

Examined and compared with vouchers and found correct.

A. J. BULL
F. A. BANNISTER } Auditors.

*January* 6, 1930.

F. N. ASHCROFT, Hon. Treasurer.

LIBRARY FUND

| Receipts. | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|
| By Balance brought forward from 1928— | | | | | | |
| 1. At Bankers, Current Account | 2 | 5 | 3 | | | |
| 2. In Office | 0 | 0 | 0 | | | |
| | | | | 2 | 5 | 3 |
| Transferred from General Purposes Account | | | | 22 | 0 | 0 |
| | | | | £24 | 5 | 3 |

## BALANCE

DECEMBER

| Liabilities. | £ | s. | d. |
|---|---|---|---|
| By In trust for a member | 1 | 14 | 2 |
| Excess of Assets over Liabilities | 2034 | 19 | 11 |
| | £2036 | 14 | 1 |

ACCOUNT.

| Payments. | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|
| To Binding of Periodicals | | | | 1 | 16 | 0 |
| Miscellaneous Printing— | | | | | | |
| 1. Notices of transference of Library to London | 1 | 7 | 6 | | | |
| 2. Library rules | 2 | 10 | 0 | | | |
| | | | | 3 | 17 | 6 |
| Transference of Library from Cambridge to London | | | | 12 | 0 | 0 |
| Librarian's Honorarium, 1929 | | | | 5 | 0 | 0 |
| Postage and other small items | | | | 0 | 8 | 2 |
| Balance, December 31, 1929— | | | | | | |
| 1. At Bankers: Current Account | 1 | 1 | 9 | | | |
| 2. In Office | 0 | 1 | 10 | | | |
| | | | | 1 | 3 | 7 |
| | | | | £24 | 5 | 3 |

Examined and compared with vouchers and found correct.

A. J. BULL
F. A. BANNISTER } Auditors.

*January* 6, 1930. F. N. ASHCROFT, Hon. Treasurer.

## SHEET

31, 1929.

| Assets. | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|
| Balances— | | | | | | |
| I. General Purposes Account: | | | | | | |
| 1. At Bankers: | | | | | | |
| (*a*) Current Account | 10 | 3 | 8 | | | |
| (*b*) Deposit Account | 170 | 0 | 0 | | | |
| 2. In Office | 0 | 9 | 9 | | | |
| | | | | 180 | 13 | 5 |
| II. Library Fund Account— | | | | | | |
| 1. At Bankers: Current Account | 1 | 1 | 9 | | | |
| 2. In Office | 0 | 1 | 10 | | | |
| | | | | 1 | 3 | 7 |
| Sale of Publications— | | | | | | |
| 1. By Publishers, April 1 to Dec. 31, 1929 | 100 | 17 | 8 | | | |
| 2. By custodian, 1929 | 3 | 15 | 9 | | | |
| | | | | 104 | 13 | 5 |
| Investments at Broker's Valuation— | | | | | | |
| 1. £1,580 5 % War Loan 1929–47 Inscribed Stock at 100¼ | 1583 | 19 | 0 | | | |
| 2. £105 4 % Consolidated Loan 1957 Inscribed Stock at 83 | 87 | 3 | 0 | | | |
| 3. £50 4 % Funding Loan 1960–90 Inscribed Stock at 85½ | 42 | 15 | 0 | | | |
| | | | | 1713 | 17 | 0 |
| Advertisement Fees, estimated at | | | | 27 | 18 | 8 |
| Arrears of Annual Subscriptions, valued at | | | | 8 | 8 | 0 |
| | | | | £2036 | 14 | 1 |

The value of the Library and that of the Stock of Publications are not included in the above assets.

*January* 14, 1930. F. N. ASHCROFT, Hon. Treasurer.

Mr. E. Heron-Allen then exhibited a so-called meteorite from Hangchow, Chekiang, China; and Mr. J. Broadhead exhibited a specimen of witherite from Nentsbury mine, Nenthead, Cumberland.

The following papers were then read :—

1. Scawtite, a new mineral from Scawt Hill, Co. Antrim : by Dr. C. E. Tilley, with a chemical analysis by Mr. M. H. Hey (p. 222).

2. The composition-plane of [010]-twins in the acid plagioclases : by Dr. F. Coles Phillips (p. 225).

3. The variation of optical properties with chemical composition in the rhodonite-bustamite series : by Mr. M. H. Hey (p. 193).

4. A preliminary account of some mineralogical and chemical changes induced by progressive metamorphism in the Green Bed group of the Scottish Dalradian : by Dr. F. Coles Phillips.

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# *A new occurrence of zunyite near Postmasburg, South Africa.*[1]

(With Plate IX.)

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With a note on the Crystallography by L. J. Spencer, F.R.S.

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WHILE I was engaged on the geological survey of the Postmasburg manganese fields during 1927 the rare mineral zunyite, a basic orthosilicate of aluminium, was discovered in some altered highly aluminous shales or flagstones. The only occurrence of zunyite so far known is in Colorado, where, according to Dana's 'System of Mineralogy',[2] it was found at the Zuñi mine, Anvil Mountain, San Juan Co., and near Red Mountain, Ouray Co.[3] At the former locality it is intimately mixed with the sulpharsenite of lead, guitermanite, and pyrite, and is also embedded in an earthy material

[1] This paper collects together the mineralogical details contained in the author's report on 'The geology of the Postmasburg manganese deposits and the surrounding country', Geological Survey of the Union of South Africa (Special Publication), Pretoria, 1929, 104 pp. [Min. Abstr., vol. 4, p. 232], with the addition of two new chemical analyses by Mr. H. G. Weall and some other new matter.

[2] J. D. Dana, System of Mineralogy, sixth edit., 1892, p. 436, and Appendix I, 1899, p. 75.

[3] These two localities are about five miles apart over the county boundary.

consisting in part of lead sulphate derived from the alteration of the associated ores. Near Red Mountain it occurs as minute tetrahedra in an altered porphyrite. Schlaepfer and Niggli [1] obtained tetrahedral crystals of a zunyite-like substance on heating $Al_2O_3$ and $SiO_2$ with water in simple molecular proportions in a bomb at 470° C.

In the Postmasburg area, situated in the northern part of the Cape Province, South Africa, zunyite has so far been found in two localities only; namely, on a low prominence or rise about 800 yards to the south-east of Lace's Goat on the farm Doornfontein (no. M. 82), and in a patch of altered shales occupying the valley at the back of the homestead on the farm Klipfontein (no. M. 24). During an early survey of this country in 1905 Dr. A. W. Rogers brought away with him some of the altered shales from the latter place, and in one of the thin sections he had cut he noticed the presence of a few small crystals of an isotropic mineral, but as no further occurrences of it could be found the mineral was not identified. This section is still available and a comparison of the isotropic mineral (the triangular crystals of which are about 0·4 mm. across) with the Doornfontein occurrence showed that it is undoubtedly zunyite. When in 1928 I was camped on Klipfontein, a search was made for this mineral in the valley but without success. Neither did any of the thin sections of several rock specimens collected reveal its presence.

The Doornfontein occurrence, on the other hand, is characterized by a fair abundance of zunyite in an altered shaly rock less than six feet thick and forming part of a small circular outlier of Gamagara beds hardly 150 yards across. This outlier gives rise to the low prominence referred to above.

*Associated Rocks.*—The Gamagara Series of the Waterberg System (probably of pre-Cambrian age), in which the zunyite occurs, embraces a succession of quartzites, highly aluminous flagstones and shales, and, along the base, lenticular bodies of a coarse ferruginous breccia or conglomerate. These beds, ranging in thickness from only a few feet to over 1,200 feet, occupy a linear-shaped tract about 38 miles long that corresponds to the trend of the Gamagara ridge of hills; they also occur in a number of isolated patches scattered over the country, outliers in an area now occupied by dolomitic limestones, banded ironstones, cherts, jaspers, shales, and andesitic lavas belonging to the Campbell Rand and Griquatown Series of the Transvaal System. These older rocks, which generally speaking form a broad

[1] M. Schlaepfer and P. Niggli, Zeits. Anorg. Chem., 1914, vol. 87, p. 56.

anticline with its western limb complicated by faults and small flexures, are unconformably overlain by the Gamagara beds.

Usually the Gamagara Series dips towards the west with angles of about 10° to 20°, but now and again there are changes in the angle and direction of dip due to the disturbances or folding the beds have undergone as a result of thrust faulting on the west, or local subsidences of the basal portions into solution cavities in the underlying dolomitic limestones. These beds have attracted considerable attention because of the recent discovery along the base of the group of extensive and rich deposits of manganese ore.

The altered rock in which the zunyite was discovered belongs to a group of red, purplish, grey, and also pale-coloured shales and flagstones of varying width up to about 130 feet thick intercalated between the ferruginous basal conglomerate and the quartzites. Immediately above the conglomerate the shale is deep-red in colour and often also pisolitic. These rocks are soft and easily cut by a hack-saw and may lead one to suppose that they are of a talcose or steatitic composition, but chemical analyses disclosed a complete absence of magnesia with, instead, alumina and silica as the main constituents. This is illustrated in the following table of analyses of three samples of rock collected.

*Table I. Analyses of highly aluminous shales.*

| | A. | B. | C. |
|---|---|---|---|
| Silica ... ... ... ... ... ... | 46·5 | 44·05 | 46·55 |
| Titania ... ... ... ... ... | 1·75 | 1·75 | 2·15 |
| Alumina ... ... ... ... ... | 42·2 | 41·35 | 42·6 |
| Chromic oxide ... ... ... ... | 0·05 | 0·05 | 0·05 |
| Ferric oxide... ... ... ... ... | 0·7 | 4·8 | 0·5 |
| Ferrous oxide ... ... ... ... | 0·2 | 0·3 | 0·15 |
| Manganese oxide ... ... ... ... | trace | trace | trace |
| Magnesium oxide ... ... ... ... | nil | nil | nil |
| Calcium oxide ... ... ... ... | trace | trace | 0·35 |
| Alkalis (sodium and potassium oxides) ... | 0·35 | 0·4 | 0·35 |
| Phosphoric oxide ... ... ... ... | 0·05 | 0·1 | 0·1 |
| Loss on ignition ... ... ... ... | 8·35 | 7·15 | 7·15 |
| Moisture ... ... ... ... ... | 0·1 | 0·1 | 0·1 |
| | 100·25 | 100·05 | 100·05 |

A, white or pale greyish shale. B, red shale. C, pale greyish shale.

Analyses by H. G. Weall, F.I.C., Government Chemical Laboratories, Johannesburg. (Previously published in the author's report, 1929, p. 35.)

From the above figures it is evident that there is not enough silica to combine with all the alumina to form one or more of the alumino-

silicate minerals. This, as seen in thin sections, is due to a great number of minute diaspore crystals strewn in a dense scaly matrix composed of two minerals, one showing high and the other low double refraction. The red colour of sample B is due to finely divided red iron oxide disseminated through the rock, but especially noticeable along the margins of laminae. The titanium in the three samples is due to the presence of minute rutile crystals.

Diaspore apparently is always present in these shaly rocks, more especially in the pale or grey coloured varieties. Moreover, its dimensions are not always microscopic, but in places the mineral shows tabular crystals that are as much as a centimetre across. In some parts of the Postmasburg area an unusual variety of rocks has resulted from the alteration of the original aluminous shales and flagstones. In the most advanced stages of metamorphism the rock has lost all properties peculiar to shales or flagstones, and become granular. Near Lace's Goat, where the zunyite was found, coarse diaspore-rock, diaspore-granulite, diaspore-zunyite-rock, and diaspore-zunyite-granulite, depending on the characteristic or main constituents of the rock and the structure shown, are to be seen. In the diaspore-rock, for example, the characteristic mineral may or may not form the major portion of the rock, but it is always embedded in a whitish or greenish scaly matrix, whereas the diaspore-granulite consists practically of diaspore grains only and does not show any signs of foliation or schistosity. Similarly the diaspore-zunyite-rock is distinguished from the granular variety. Typical of the zunyite locality on Klipfontein again are diaspore-, kaolin-, diaspore-kaolin-, quartz-diaspore-, diaspore-leverrierite-,[1] diaspore-leverrierite-quartz-, and ferruginous diaspore-rocks.

It is difficult to explain the alteration of these rocks. The presence of the diaspore and zunyite cannot be attributed to thermal metamorphism dependent on heat emanating from intrusive bodies. Acid or basic plutonic rocks are not present in the rock formations that appear on the surface in the Postmasburg area. The only igneous rocks are the Ongeluk lavas, much older than the altered rocks, some doleritic dikes, and a few kimberlite pipes, that have had no appreciable effect on the surrounding rocks.

The possibility of the alterations having been effected by dynamic metamorphism in the form of crustal movements was also considered,

[1] The mineral appears to be one of the leverrierite group, but its determination as such was unsatisfactory.

but here again the shales that are altered most do not occur in localities where the Gamagara beds indicate a greater degree of disturbance than usual. Moreover, the mineral arrangement is not suggestive of shearing stresses; foliation and schistosity, although seen occasionally, are not characteristic of these rocks. Apparently, then, the changes observed in the rocks have either been set up by circulating waters or some other process without the conditions of high temperature and great mechanical force.

The genesis of these highly aluminous rocks is also not clearly understood at present. They appear to me to have been derived from the clayey or lateritic residue left by the decomposition of some rock, and subsequently deposited as a sediment, because they show bedded structure and occasional detrital grains of quartz, chert, and ironstone. What appears to be more likely is that they represent the insoluble residual slime, probably a very small fraction, of a great mass of Campbell Rand limestones and dolomites removed by solution.

*Mode of Occurrence.*—On Doornfontein farm the zunyite occurs in two ways: either it forms curious patches in the coarse diaspore-rock (pl. IX, fig. 1), or its crystals are roughly arranged in layers or disseminated through a rock in which the diaspore is only of microscopic dimensions. The patches, frequently spherical or oval-shaped, range up to about half-an-inch or more in length; they are irregularly scattered through the rock, several of them now and again adjoining one another, while elsewhere only an isolated patch or two are seen. Their distribution in the coarse diaspore-rock appears to be confined to an indistinct layer only a few inches thick. These patches are really saccharoidal aggregates of glassy zunyite with very little impurity in the form of other minerals present. The crystals are beautiful little tetrahedra, hardly more than half a millimetre across.

In the second mode of occurrence, the zunyite crystals on the whole are larger, individuals of two and three millimetres across being quite common. The crystals are perfectly idiomorphic, and the solid corners of several tetrahedra are replaced by faces belonging to the negative tetrahedron. They are flesh to pinkish coloured, transparent to opaque, while in the centres of many are patches, often also tetrahedral shaped, of a dark red impalpable dusty matter. It seems to me that these patches consist of a fine haematite dust that got enclosed as the zunyite crystals developed.[1] Support is lent to this

[1] Similar dark red patches were noticed in several diaspore crystals.

supposition by the higher percentages of iron oxide indicated by analyses A and B in table IV, as compared with the analysis in table II of the glassy clear zunyite in the aggregate form. Haematite, moreover, occurs in great abundance in some of the associated rocks. The rock in which these zunyite crystals occur is very fine-grained, somewhat friable and, as seen under the microscope, largely made of a granular aggregate of diaspore with lesser amounts of scaly minerals such as kaolin and possibly pyrophyllite or leverrierite (pl. IX, figs. 2 and 3).

*Physical Characters.*—The mineral as noted above is cubic and occurs in the form of small perfect tetrahedra with the solid corners of some individuals replaced now and again by faces of the negative tetrahedron. Two measurements taken on a goniometer of the interfacial angle gave 109° 35′ and 109° 50′ respectively, the small difference from the theoretical angle (109° 28′) being accounted for by the multiple images given by the crystal faces. Occasionally one may find two crystals, usually of different magnitudes, interpenetrating so that the solid angles of one project through the triangular faces of the other. In some instances this appears to be the result of twinning about a triad axis. That twinning, however, is actually represented could not be satisfactorily confirmed by goniometric methods on account of the small size of the crystals and the multiple reflections obtained from faces. The mineral shows distinct octahedral cleavage; it has a vitreous to almost adamantine lustre; the hardness appears to be about 7, and the mineral is brittle. Two determinations of the specific gravity by the pyknometer method gave 2·884 at 25·2° C. and 2·891 at 20·3° C. respectively.[1] The refractive index from readings taken by the liquid immersion method at 19·5° C. and using sodium-light was found to be 1·600.

In thin rock sections under the microscope, zunyite always shows idiomorphic outlines, while there is a tendency for the crystals to collect into roundish-shaped clusters or aggregates (pl. IX, fig. 3). The mineral is perfectly isotropic, showing no signs of optical anomalies. Apart from the Klipfontein occurrence and those crystals on Doornfontein enclosing the fine haematite dust above referred to, the mineral is practically free of inclusions except for a few minute doubly refracting particles, some of which are rutile. As regards the manner in which zunyite and the other rock constituents are associated, the thin sections show that diaspore may either wrap round or enclose

[1] Corrected values $D_4^{25\cdot2} = 2\cdot873$ and $D_4^{20\cdot3} = 2\cdot884$.

the zunyite; while a scaly or fibrous aggregate, composed partly of kaolin and partly of the other more strongly doubly refracting aluminous mineral, occupies the interstices between the diaspore and zunyite or forms the matrix in which they are set (pl. IX, figs. 4 and 5).

In the thin section cut from the rock sample collected by Dr. A. W. Rogers in 1905 on Klipfontein, diaspore and zunyite crystals are evenly scattered through a fine-grained groundmass composed of quartz, kaolin, and the other scaly mineral with the stronger birefringence, and give rise to a porphyroblastic texture. The diaspore is much more abundant than the zunyite. Both minerals are crowded with the constituents of the groundmass so much so that in the case of the zunyite it is practically impossible to distinguish the outlines of the crystals in ordinary light; only when the nicols are crossed do the isotropic triangular crystals stand out with great clearness.

*Chemical Characters.*—The zunyite when heated in a bulb-tube yields water that has a decided acid reaction. Before the blowpipe the mineral glows brilliantly, the sharp edges show not the slightest sign of fusion, and the whole becomes white, opaque and porcelain-like. It is insoluble in cold or hot acids. Material for quantitative analysis was carefully picked out from the glassy aggregates or clusters in the coarse diaspore-rock and submitted to the Government Chemical Laboratories. While great care was taken to get a pure product it is quite possible that fine cleavage-flakes of diaspore and minute specks of the scaly matrix escaped unnoticed. The amount of material available for analysis was only 3·9 grams. The following were the results obtained:

*Table II. Analysis of Zunyite from Doornfontein farm.*

| | |
|---|---|
| Silica ... ... ... ... ... | 29·1 % |
| Alumina ... ... ... ... | 54·25 |
| Ferric oxide ... ... ... ... | 0·5 |
| Magnesium oxide ... ... ... | trace |
| Calcium oxide ... ... ... | trace |
| Alkali oxides ... ... ... ... | trace |
| Phosphoric oxide ... ... ... | 0·15 |
| Chlorine ... ... ... ... | 2·45 |
| Fluorine ... ... ... ... | 0·8 |
| Loss on ignition ... ... ... | 15·35 |
| Moisture ... ... ... ... | 0·9 |
| | 103·50 |

To this Dr. J. McCrae adds the following:—[1]

Oxygen equivalent to chlorine and fluorine amounts to 0·9 per cent. Making a deduction of this amount the analysis accounts for 102·6 per cent. This excess over 100 per cent. makes it probable that none of the constituents has been under-estimated. The excess may in some way be connected with the loss on ignition which probably includes more than water of constitution: this suggestion is made because it was found that the ignited material contained no chlorine. If during the ignition the chlorine had been expelled (as was apparently the case) its place would, no doubt, be taken by oxygen: the loss due to this would be minus 2·45 plus 0·55 or 1·9 per cent. It is, therefore, possible that the water of constitution is approximately 15·35 (loss on ignition) minus 1·9, or 13·45 per cent. It is regretted that the amount of material available was not sufficient to permit of a direct determination of the water of constitution. If the water of constitution be taken as 13·45 per cent. then, making due allowance for oxygen equivalent to the determined quantities of chlorine and fluorine, the analysis accounts for 100·7 per cent. of material. The analysis as so readjusted is given under I in table III, where other analyses of zunyite are added for comparison.

*Table III. Analyses of Zunyite.*

| | I. | II. | III. | IV. |
|---|---|---|---|---|
| $SiO_2$ ... ... ... | 29·1 | 24·33 | 24·11 | 24·15 |
| $Al_2O_3$ ... ... ... | 54·25 | 57·88 | 57·20 | 57·68 |
| $Fe_2O_3$ ... ... ... | 0·5 | 0·20 | 0·61 | 0·18 |
| MgO ... ... ... | trace | — | — | — |
| CaO ... ... ... | trace | — | 0·11 | — |
| $Na_2O$ ... ... ... | trace | 0·24 | 0·48 | 0·31 |
| $K_2O$ ... ... ... | trace | 0·10 | — | 0·18 |
| $Li_2O$ ... ... ... | — | trace | — | — |
| Cl ... ... ... | 2·45 | 2·91 | 2·62 | 2·90 |
| F ... ... ... | 0·8 | 5·61 | 5·81 | 5·19 |
| $P_2O_5$ ... ... ... | 0·15 | 0·60 | 0·64 | 0·52 |
| $H_2O+$ ... ... ... | 13·45 | 10·89 | 11·12 | 11·12 |
| $H_2O-$ ... ... ... | 0·9 | — | — | — |
| | 101·60 | 102·76 | 102·70 | 102·23 |
| Less O for F and Cl ... | 0·90 | 3·02 | 3·03 | 2·83 |
| | 100·70 | 99·74 | 99·67 | 99·40 |
| Sp. gr. ... ... ... | — | 2·875 | 2·876—2·904 | 2·878 |

I. Doornfontein farm, Postmasburg, Cape Province, South Africa. J. McCrae in L. T. Nel, The geology of the Postmasburg manganese deposits, Geol. Survey S. Africa, Pretoria, 1929, p. 39.

II. Zuñi mine, Silverton, San Juan Co., Colorado. W. F. Hillebrand, Proc. Colorado Sci. Soc., 1885, vol. 1 (for 1883–4), p. 124; Bull. U.S. Geol. Survey, 1885, no. 20, p. 100.

III. Charter Oak mine, Red Mountain, Ouray Co., Colorado. S. L. Penfield, Amer. J. Sci., 1893, ser. 3, vol. 45, p. 397.

IV. Zuñi mine, Colorado. B. Gossner and F. Mussgnug, Centralblatt Min., Abt. A, 1926, p. 149; B. Gossner, Neues Jahrb. Min., Abt. A, 1926, vol. 55, p. 319 [Min. Abstr., vol. 3, p. 433].

[1] Reprinted, together with the above analysis (Table II), from the 1929 report (pp. 38–39).

The formula[1] assigned to zunyite is $Al_8(OH,F,Cl)_{12}(SiO_4)_3$. The amount of chlorine in the specimens (say 2·5 per cent.), shows that whereas a halogen-free zunyite might be formulated as $4Al(OH)_3.2Al_2O_3.3SiO_2$, the specimens contain chlorine replacing hydroxyl approximately to the extent expressed in the (doubled) formula $AlCl(OH)_2.7Al(OH)_3.4Al_2O_3.6SiO_2$. The results quoted indicate that in the American specimens hydroxyl is replaced by fluorine to the extent expressed by the (doubled) formula $AlCl(OH)_2.2AlF_2(OH).5Al(OH)_3.4Al_2O_3.6SiO_2$, but in the South African specimen hydroxyl has been replaced only to an extent approximately represented by the (quadrupled) formula

$$2AlCl(OH)_2.AlF(OH)_2.13Al(OH)_3.8Al_2O_3.12SiO_2 \text{ or}$$
$$AlCl_2F.15Al(OH)_3.8Al_2O_3.12SiO_2.$$

A compound of this last formula would give the following analytical values:

| | |
|---|---|
| Silica ... ... ... ... ... ... ... | 25·4 % |
| Alumina ... ... ... ... ... ... ... | 57·6 |
| Chlorine ... ... ... ... ... ... ... | 2·5 |
| Fluorine ... ... ... ... ... ... ... | 0·7 |
| Water of constitution ... ... ... ... ... | 14·65 |
| | 100·85 |
| Deduct oxygen equivalent to chlorine and fluorine... | 0·85 |
| | 100·00 |

On another visit to the Doornfontein locality a year later further samples of zunyite-bearing rocks were collected. From these, samples were selected in which zunyite is scattered as single crystals or more closely gathered into streaks and bands. To separate the zunyite from the other constituents the rocks were crushed, and the material introduced into a bell-jar slightly moistened on the inside with alcohol. It was found that after rotating the jar a few turns, setting it down and tapping the sides with the hands many zunyite crystals adhered to the glass while the other minerals or rock particles dropped down. On repeating this a few times a product was eventually obtained practically free from foreign matter, and moreover, it was possible to get two or three grades of coarseness. Foreign particles that still remained were then carefully picked out under the binocular microscope. Two samples of zunyite crystals, a coarser and a finer product, were then submitted to the Government Chemical Laboratories for analyses. The average size of the crystals of the coarser

[1] W. F. Hillebrand's original (1885) empirical formula $H_{18}Al_{16}Si_6(O,F,Cl)_{45}$ was modified by P. Groth in 1889 (Tab. Übers. Min., 3rd edit., p. 104) as $[SiO_4]_3Al_2[Al(OH,F,Cl)_2]_6$, representing a basic orthosilicate analogous to the garnet formula. B. Gossner and F. Mussgnug in 1926, insisting on a ratio Si : Al = 1 : 3, gave as alternative formulae $SiO_2.AlOF.2AlO_2H$ or $SiO_2.AlF(OH)_2.2AlO_2H$ and $2SiO_2.2AlOF.3AlO_2H.AlO_3H_3$; while later, in order to conform with the results given by X-ray analysis, Gossner again readjusted the formula to $3SiO_2.3AlO(F,Cl).4AlO_2H.2AlO_3H_3$.

product would be about 1 mm. across. Many crystals in both samples had little red spots of haematite dust in the centre, which accounts for the presence of iron as shown in the analyses. The samples gave the following results : those under A for the finer grade, and those under B for the coarser grade. The values given under ' water of constitution ' are the results of the determination of the amounts of combined water in the mineral and are not merely determined by loss on ignition. Lithium could not be detected.

*Table IV. New analyses of Zunyite from Doornfontein farm.*
(By H. G. Weall, F.I.C., Government Chemical Laboratories, Johannesburg.)

| | A. | B. |
|---|---|---|
| Silica ... ... ... ... | 24·25 | 24·1 |
| Titania... ... ... ... | trace | trace |
| Alumina ... ... ... | 56·75 | 56·85 |
| Ferric oxide ... ... ... | 1·3 | 1·45 |
| Magnesium oxide ... ... | 0·4 | 0·3 |
| Calcium oxide... ... ... | 0·35 | 0·2 |
| Sodium oxide ... ... ... | 1·65 | 1·45 |
| Potassium oxide ... ... | trace | trace |
| Chlorine ... ... ... | 3·5 | 4·8 |
| Fluorine ... ... ... | 0·5 | 0·4 |
| Phosphoric oxide ... ... | 0·25 | 0·25 |
| Water of constitution ... | 11·4 | 11·65 |
| Moisture ... ... ... | 0·4 | 0·35 |
| | 100·75 | 101·80 |
| Less O for F and Cl ... ... | 1·0 | 1·3 |
| Total ... ... ... ... | 99·75 | 100·50 |
| Sp. gr. (corrected) ... ... | 2·884 | 2·873 |

The composition of this mineral is thus very similar to that of the zunyite from Colorado, but the lower fluorine content with, apparently now and again, a higher chlorine percentage, serves to distinguish the South African mineral. The fluorine in the Postmasburg zunyite appears to be largely replaced by hydroxyl.

*Acknowledgements.*—In conclusion I should like to thank Mr. F. C. Partridge, of the Geological Survey, for his assistance in the determination of the physical and chemical properties, Prof. L. C. de Villiers and Mr. D. L. Scholtz of the Transvaal University College for their assistance in measuring the interfacial angle and refractive index of the zunyite. Dr. J. McCrae and Mr. H. G. Weall of the Government Chemical Laboratories also deserve my best thanks for the analyses of the highly aluminous rocks and zunyite, and to the former I am also indebted for the discussion of the results shown in Tables II and III.

*Note on the crystallography of zunyite.*

By L. J. Spencer.

Specimens from the interesting new occurrence of zunyite in South Africa were generously sent in 1928 by the Director of the Geological Survey of the Union of South Africa for the mineral collection of the British Museum, and during my visit to Pretoria in 1929 Dr. L. T. Nel kindly handed over to me a further supply of material. A crystallographic study made on the two lots of crystals separated from the rock for analyses A and B (Table IV, p. 216) enables a few more points to be added to his paper. Twinning about a triad axis is suggested by Dr. Nel, and this I have been able to confirm. Rather than incorporating this extra matter in his paper without his knowledge and consent, I have taken the liberty of adding an appendix. His present paper, I may further explain, is the result of my suggestion that his account of this remarkable occurrence of a rare and interesting mineral should be given more prominence in mineralogical literature than would be obtained in a geological report on the manganese ore-deposits. In an abstract[1] of his report there is, for example, only the barest mention of the mineral in question.

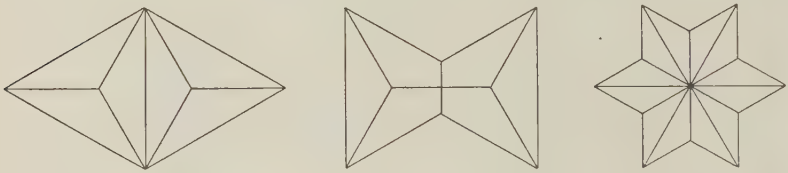
The two lots, A and B, of separated crystals show certain differences. Those of lot A are smaller, varying only slightly from an average size of 1 mm. along the tetrahedral edge, and lighter in colour with smaller amounts of enclosed red iron oxide as central spots in the crystals. At first sight they appear to be simple tetrahedra, but under the microscope they all show small faces of the complementary tetrahedron. No twinned crystals were found in this lot. Crystals of lot B are rather larger ($1\frac{1}{2}$–2 mm. edge) and darker in colour with a larger nucleus of enclosed foreign material. On these crystals the complementary tetrahedron is more conspicuously developed, especially on the twinned crystals. About one per cent. of the crystals were found to be twins. One specimen of the rock with numerous embedded zunyite crystals yielded a higher percentage of twinned crystals.

The crystals are in all cases singly and sharply developed with brilliant faces on all sides. Only very rarely do they show broken corners or an irregular intergrowth of two or more crystals. The larger faces of the positive tetrahedron *o* (111) are brilliant and to all

[1] Min. Abstr., vol. 4, p. 232.

appearance quite smooth, but on the goniometer they give scattered reflected images. They show low pyramids of growth and lines parallel to the tetrahedral edges. The smaller faces of the negative tetrahedron $o'$ $(\bar{1}11)$ are dull and pitted and give only blurred images. In their outer portions the crystals are colourless and transparent, and it is only the red nucleus that gives a pink tinge by reflection to the crystal as a whole.

Twinning, which has not previously been described for zunyite, is by rotation about a triad axis with interpenetration. Two tetra-



1 *a*. 1 *b*. 1 *c*.

Fig. 1. Tetrahedra twinned by rotation of 60° or 180° about a triad axis. Plans viewed along the twin-axis.

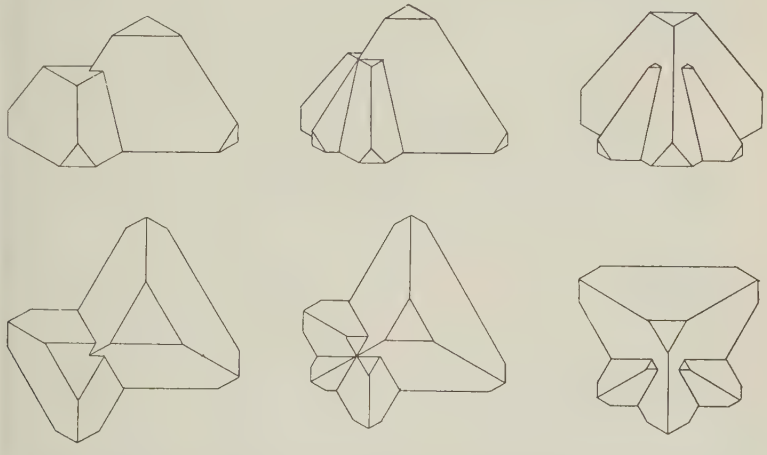
hedra, in twinned position by a rotation of one of them through either 60° or 180° about a triad axis, may be joined together symmetrically in three different ways. Figs. 1*a* and *b* show the combination on one or other side of a plane parallel to the twin-axis, this composition-plane being a face of the icositetrahedron {211}. If the twin-axis is [111], these faces may be $(\bar{1}\bar{1}2)$, $(1\bar{2}1)$, or $(\bar{2}11)$, or their parallels. Fig. 1*c* shows the complete interpenetration of the two tetrahedra. In all three cases the tetrahedral faces (111) and $(\bar{1}\bar{1}\bar{1})$ perpendicular to the twin-axis are common to the two individuals. Interpenetration-twins, as in fig. 1*c*, were figured for tetrahedrite by W. Haidinger[1] in 1824. Contact-twins of the (*a*) and (*b*) kinds have been described for tetrahedrite by A. Sadebeck.[2]

The zunyite twins may be described as interpenetration-twins, but no example was found in which the apices of the two crystals are coincident, as in fig. 1*c*. One individual is always smaller than the other. The twin represented in fig. 2*a* shows some resemblance to the contact-twin in fig. 1*b* with only a slight overlap or interpenetra-

[1] W. Haidinger, Edinburgh Journ. Sci., 1824, vol. 1, p. 60, pl. 3.

[2] A. Sadebeck, Zeits. Deutsch. Geol. Gesell., 1872, vol. 24, p. 427, pls. 16, 17; Angewandte Krystallographie, Berlin, 1876, pl. 3. See also W. J. Lewis, Treatise on Crystallography. Cambridge, 1899, p. 473.

tion. In fig. 2*b* the smaller crystal is pushed farther into the larger crystal, and in fig. 2*c* still farther. In the last figure the two separate portions of the smaller individual separately occupy positions relatively to the larger crystal as in fig. 1*a*; though taken together their



2*a*. 2*b*. 2*c*.

FIG. 2. Twinned crystals of zunyite from Postmasburg, South Africa. Clinographic drawings and plans.

relative position is as in fig. 1 *b*. Often there are quite small projecting corners from two (never three) of the faces of an otherwise simple tetrahedron. The re-entrant angle between the faces of the two individuals was measured as 56° 17′ (calculated 56° 15′).

When a corner of the tetrahedron is chopped off, the fractured surface appears to be irregular, but in the goniometer it gives a poor reflected image in the position of the complementary tetrahedron. The crystals therefore have a poor octahedral cleavage.

The degree of hardness was determined by embedding a minute crystal in sealing-wax on a holder. The mineral scratched quartz, but only with difficulty. On the other hand, a crystal still embedded in the rock is more readily scratched by topaz. The hardness may then be placed at $7\frac{1}{4}$.

Being tetrahedral, the crystals would be expected to be pyroelectric. They were tested for this property by the simple method of dusting over the cooling crystals with a mixture of red-lead and

flowers of sulphur, a small tetrahedron of boracite being used for comparison, but with a negative result.

The refractive index for light of three wave-lengths was determined by the prism method through two tetrahedral faces, for which purpose the faces had to be artificially polished. The results obtained on two of the larger crystals (of 2 mm. edge) from the lot used for analysis B are:

| Li. | Na. | Tl. | $n_{Tl-Li}$. |
|---|---|---|---|
| 1·5969 | 1·5996 | 1·6026 | 0·0057 |
| 1·5969 | 1·5997 | 1·6025 | 0·0056 |

Previous determinations of the refractive index of zunyite on material from the Zuñi mine, Colorado, are:

E. S. Larsen (1921)[1] ... ... ... $n = 1{\cdot}589 \pm 0{\cdot}003$.
M. Albis (1921)[2] ... ... ... $n_D = 1{\cdot}6022$ (and other wave-lengths).
B. Gossner and F. Mussgnug (1926)[3] $n_{Na} = 1{\cdot}595$.

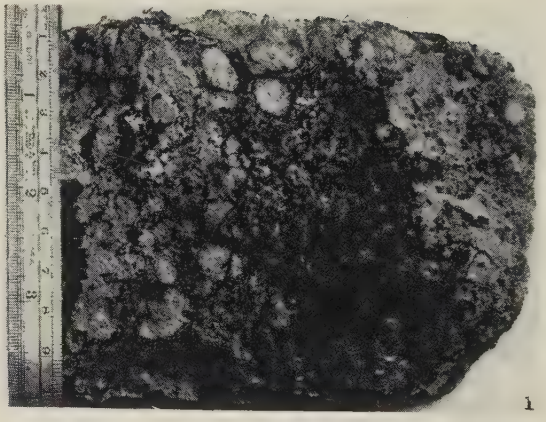
The more accurate determinations of M. Albis by the prism method when compared with those for the South African mineral affords perhaps a correlation with the chemical composition. Judging from the analyses in Table III alone, it would seem that there is a slight decrease in the refractive index as fluorine is replaced by hydroxyl. This, however, is contrary to the result obtained by S. L. Penfield[4] in 1894 for topaz and herderite. Evidently this effect is counteracted by the larger percentage of chlorine shown in analysis B of Table IV.

[1] E. S. Larsen, Bull. U.S. Geol. Survey, 1921, no. 679, p. 160.

[2] Matilde Albis, Rend. R. Accad. Lincei, Cl. Sci. Fis., Roma, 1921, ser. 5, vol. 30, sem. 2, p. 472 [Min. Abstr., vol. 2, p. 43]. Determinations are given for six lines: B 1·5975, C 1·5991, D 1·6022, E 1·6048, F 1·6085, G 1·6124, with dispersion, $n_{G-B} = 0{\cdot}0149$.

[3] B. Gossner and F. Mussgnug, Centralblatt Min., Abt. A, 1926, p. 149 [Min. Abstr., vol. 3, p. 433].

[4] S. L. Penfield, Abstract in Min. Mag., 1895, vol. 11, p. 42.



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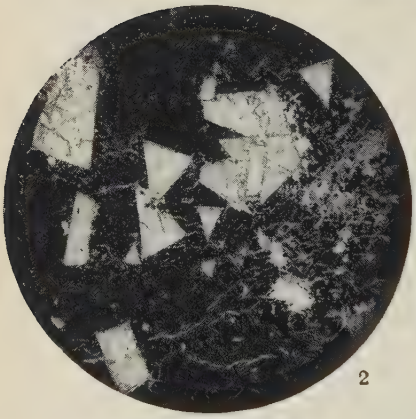

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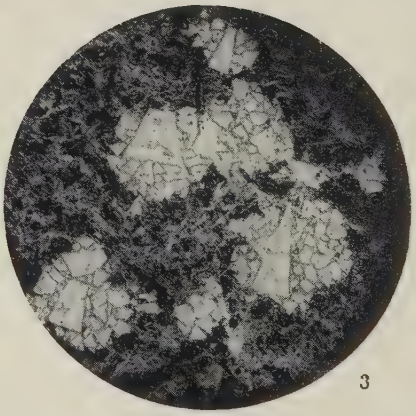

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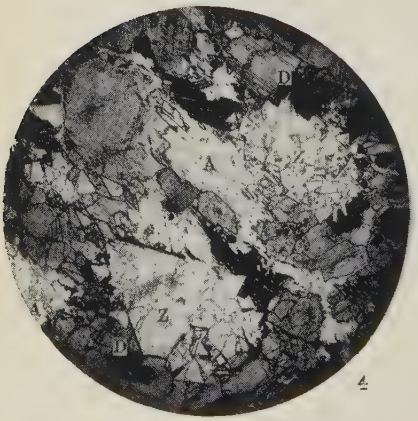


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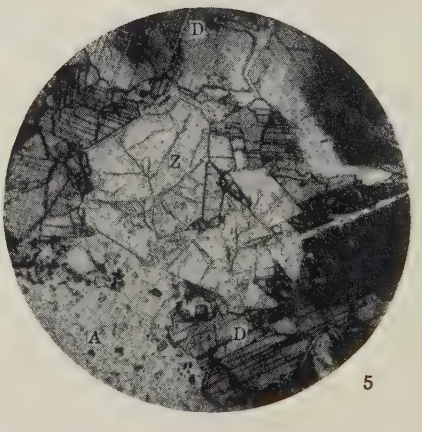


5

L. T. Nel: Zunyite from Postmasburg, South Africa.

## Explanation of Plate IX.

Zunyite from Doornfontein farm, Postmasburg, Cape Province, South Africa. (Figs. 2–5, Photomicrographs of rock sections.)

Fig. 1. Rounded or oval-shaped white patches of zunyite crystals in a coarse diaspore-rock. The dark crystals of diaspore are set in a scaly aggregate of aluminous minerals such as kaolin. × ½

— 2. Zunyite crystals in a granular aggregate of diaspore. ×8·5.

— 3. Clusters of zunyite crystals in a groundmass composed of dark diaspore crystals and white scaly minerals such as kaolin and possibly pyrophyllite or leverrierite. ×8·5.

— 4. Triangular zunyite crystals (Z) associated with diaspore (D) with a scaly aggregate (A) of kaolin and another alumino-silicate mineral with stronger birefringence. ×8·5.

— 5. Illustrating diaspore (D) enclosing or wrapping round zunyite (Z) crystals. (A) is a scaly aggregate composed partly of kaolin and partly of another scaly mineral such as leverrierite or pyrophyllite. ×21.

# *Scawtite, a new mineral from Scawt Hill, Co. Antrim.*

By C. E. Tilley, B.Sc., Ph.D., F.G.S.
Lecturer in Petrology, University of Cambridge.
With a chemical analysis by M. H. Hey, B.A., B.Sc.
Mineral Department, British Museum of Natural History.

[Read November 5, 1929.]

THE mineral now briefly described occurs as a rare constituent of the zone of hybrid rocks formed by assimilation of limestone by the dolerite intrusion at Scawt Hill, Co. Antrim.[1] It is found particularly in intimate association with the melilite-bearing types of this hybrid zone and is a constituent of some of the late-formed vesicles in these rocks. The minerals associated with it in the vesicles are chiefly calcite, thomsonite, and another zeolitic mineral as yet undetermined. These vesicles are most frequently enclosed by a ground rich in melilite, or they may occur within large crystals of melilite. In some cases the mineral forms minute venules cutting through the melilite, suggesting that it is derived in part by attack of residual solutions upon the melilite itself. All the evidence clearly indicates that the mineral is among the latest products of consolidation of the hybrid zone.

In the specimens examined, the habit is that of plates flattened in the plane of the principal cleavage. Frequently these form subparallel or slightly divergent clusters. Owing to mutual interference and intergrowth with the surrounding minerals no well-defined crystals can be isolated. The largest individuals met with do not exceed 1·5 mm. in length.

The physical properties are as follows. The density is 2·77, as determined by suspension in a mixture of bromoform and benzene, which was afterwards weighed in a pyknometer. The hardness is $4\frac{1}{2}$–5. The mineral is colourless, with a vitreous lustre. Investiga-

[1] C. E. Tilley, Min. Mag., 1929, vol. 22, p. 77; Geol. Mag., 1929, vol. 66, p. 347.

tion of the powder derived by crushing clusters of grains shows that the mineral has one perfect cleavage. Such cleavage fragments form excellent material for optical examination.

*Optical properties.*—By immersion in liquids the refractive indices have been determined as $\alpha$ 1·597, $\beta$ 1·606, $\gamma$ 1·621. The mineral is optically positive. The perfect cleavage is normal to a line between an optic axis and the obtuse bisectrix. These cleavage flakes show the trace of a second cleavage at right angles to the first, the extinction being parallel to this edge, which is the trace of the optic axial plane. By rotating such sections in a thick liquid, such as cedar-wood-oil or Peru balsam, the fragments may be brought to lie on this second cleavage, the interference-figure of which shows that it is alined parallel to the optic axial plane. The extinction-angle of such sections between $\gamma$ and the trace of the perfect cleavage is 29°. The mineral is therefore probably monoclinic. These data were confirmed by examination on the rotating stage, from which it can be shown that the normal to the perfect cleavage subtends an angle of 24° with an optic axis, the optic axial angle being approximately 2V 74°. The second cleavage is therefore taken as (010) and the perfect cleavage can be referred to (001). The orientation is then $\beta = b$, $\gamma : (001) = 29°$ (fig. 1). These optical properties cannot be associated with any known mineral, and it seemed clear that the mineral has hitherto not been described.

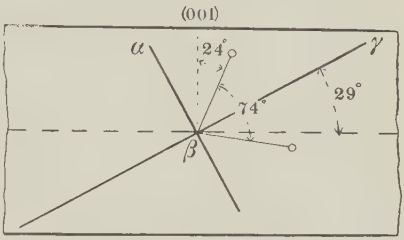


Fig. 1. Optical orientation of scawtite on the plane of symmetry (010).

*Chemical Composition.*—Micro-chemical tests show that the mineral is readily decomposed by weak hydrochloric acid with a marked effervescence, leaving a gelatinous residue. Furthermore, abundant lime, as shown by the oxalate test, is indicated. Qualitative tests thus indicate the presence of $SiO_2$, CaO, and $CO_2$.

In order to obtain sufficient material for analysis the crushed material of the vesicles was first hand-picked under a low-power lens, and the material thus selected was finally separated from calcite, thomsonite, and other minerals under the microscope. Owing to the intimate intergrowth of these minerals this separation was a long and tedious process. Sufficient material (0·0812 gram)

was, however, obtained, and Mr. M. H. Hey kindly undertook the analysis with the following results:

| | | % | Molec. Ratios. | 3. | 4. | 5. | 6. |
|---|---|---|---|---|---|---|---|
| CaO | ... | 46·4 | 0·828 | 5·96 | 4·13 | 5·96 | 4·13 |
| $SiO_2$ | ... | 34·2 | 0·570 | 4·10 | 2·84 | 4·27 | 2·97 |
| $CO_2$ | ... | 18·0 | 0·409 | 2·95 | 2·04 | 2·95 | 2·04 |
| | | 98·6 | | | | | |

These results would indicate a formula $6CaO.4SiO_2.3CO_2$, which agrees better with the determined figures (column 3) than a formula $4CaO.3SiO_2.2CO_2$ (column 4); but it is possible that the major portion of the loss (1·4%) may be silica, owing to the difficulty of removing all the silica from the flask in which the carbon dioxide estimation was made. If we assume this to be the case, the molecular ratio of silica becomes 0·593, and the second formula then agrees better (column 6) than the first (column 5). The formulae may be written $3CaCO_3.3CaO.4SiO_2$ and $2CaCO_3.Ca_2Si_3O_8$ respectively.

It is proposed to designate this new mineral scawtite, from the original locality, Scawt Hill, Co. Antrim. Although the exact formula to be assigned to it must remain a little uncertain till larger quantities of pure material are available for analysis, the results obtained show clearly that it is a well-individualized species distinct from any other described mineral. The only other comparable mineral is spurrite, which has the composition $5CaO.2SiO_2.CO_2$ or $2Ca_2SiO_4.CaCO_3$. To this, scawtite bears no resemblance in its physical or optical properties. In rock-slices, scawtite is not a strikingly distinctive mineral. Cleavages are frequently ill-developed. It is recognized by its moderate refraction ($\beta$ 1·606) and double refraction (0·024), positive sign, and positive or negative character of the elongation when parallel to the *b*-axis. In lath-shaped sections, the optic axial plane across the length, and the extinction-angle $\gamma : a = 29°$ on optic axial plane sections, are important diagnostic criteria.

# *Pericline and acline-A twins in the acid plagioclases.*

F. Coles Phillips, M.A., Ph.D., F.G.S.
Fellow of Corpus Christi College, Cambridge.

[Read November 5, 1929.]

THE orientation of the 'rhombic section', the composition-plane of the pericline twin, in the plagioclase felspars as an index of the chemical composition of the felspar was first utilized by G. vom Rath, who measured the angle $\sigma$ on the face (010) between the trace of the composition-plane and the edge [010,001]. Duparc and Reinhard, in their comprehensive work on the determination of the plagioclases,[1] quote two series of values for this angle, one due to Wülfing and the other to Becke. They comment on the discordance between the two series, most marked at the acid end, and add that they did not then possess suitable material for critical determinations on their own account. Wülfing's [2] values are given in the form of a curve based on data assembled by Schmidt,[3] and those of Becke were first given in a paper on the felspars in crystalline schists.[4]

The apparent enormous discrepancy between these two series of $\sigma$ values as given by Duparc and Reinhard is partly due to a misquotation from Becke. These writers (loc. cit., p. 4) base their data for albite on a description by Grosspietsch of crystals from Greenland containing 0·5% An. The correct value of $\sigma$ for this percentage of anorthite has been read from Wülfing's curve, but that quoted as Becke's value is actually his value for a felspar containing 5·0% An. The values originally given by Becke are founded on data by Schuster.[5] Reference to this author's complete list will show that

[1] L. Duparc and M. Reinhard, Mém. Soc. Phys. Hist. Nat. Genève, 1924, vol. 40, p. 26. [Min. Abstr., vol. 3, p. 34.]

[2] E. A. Wülfing, Sitzungsber. Heidelberg. Akad. Wiss., Math.-naturw. Kl., 1915, Abt. A, Abh. 13. [Min. Abstr., vol. 1, p. 390.]

[3] E. Schmidt, Chemie der Erde, 1915, vol. 1, pp. 351–406; Inaug.-Diss. Heidelberg, 1916. [Min. Abstr., vol. 1, p. 390.]

[4] F. Becke, Denkschr. Akad. Wiss. Wien, Math.-naturw. Kl., 1913, vol. 75, p. 105.

[5] M. Schuster, Min. Petr. Mitt. (Tschermak), 1880, vol. 3, p. 24.

one is justified in drawing a smooth curve through these arbitrarily selected values, but extrapolation of this curve still gives a $\sigma$ value for pure albite much lower than that of Wülfing.

In the Fedorov method of felspar determination by means of the universal stage, the angle measured between (001) and the rhombic section is the true dihedral angle $\sigma'$, not theoretically identical with the angle $\sigma$ between the traces of (001) and the rhombic section on the face (010). From the crystallographic constants of the felspars this angle $\sigma'$ is readily calculated.[1] If the Schmidt-Wülfing values for the angles (001) : (010) and the axial angle $\gamma$ are employed in this recalculation, the following series is obtained:

| An % ... | 0. | 5. | 10. | 20. | 30. |
|---|---|---|---|---|---|
| $\sigma'$ (calc.) ... | 38° 54′ | 24° 56′ | 15° 28′ | 7° 19′ | 3° 14′ |

These, it will be observed, differ from the Wülfing values for $\sigma$ by an amount less than the experimental error. They are plotted in fig. 1.

The literature of felspar determinations by Fedorov methods affords few significant data which can be compared with these theoretical conclusions. T. Barth, however, has recently published the results of fourteen measurements on pericline twins of acid felspars [2] showing values up to 37° for pure albite. On the basis of his measurements, Barth concludes that the position of the rhombic section, though showing a certain tendency to a relationship with the chemical composition, is not determined merely by this factor; that the rhombic section must not be considered a crystallographic constant; and that above all from the orientation of this section one must not draw definite conclusions as to the composition of a plagioclase.

These conclusions appear to leave out of account a number of considerations. Duparc and Reinhard separate from the true pericline twin with twin-axis [010] and variable composition-plane, the twin acline-A, in which the twin-axis is [010] as before but the composition-plane is invariable, being (001). M. Gysin [3] has shown quite definitely that the acline-A twin has a real existence in the more basic plagioclases. His thirty-nine plotted examples show also

[1] See, for example, W. J. Lewis, Crystallography. Cambridge, 1899, p. 550.

[2] T. Barth, Zeits. Krist., 1928, vol. 68, pp. 616–618. [Min. Abstr., vol. 4, p. 37.]

[3] M. Gysin, Schweiz. Min. Petr. Mitt., 1925, vol. 5, pp. 128–146. [Min. Abstr., vol. 3, p. 520.]

considerable divergence from the standard curves of migration, and he accounts for this partly in the experimental error incidental to the method and partly in the modifying influence, at present undeter-

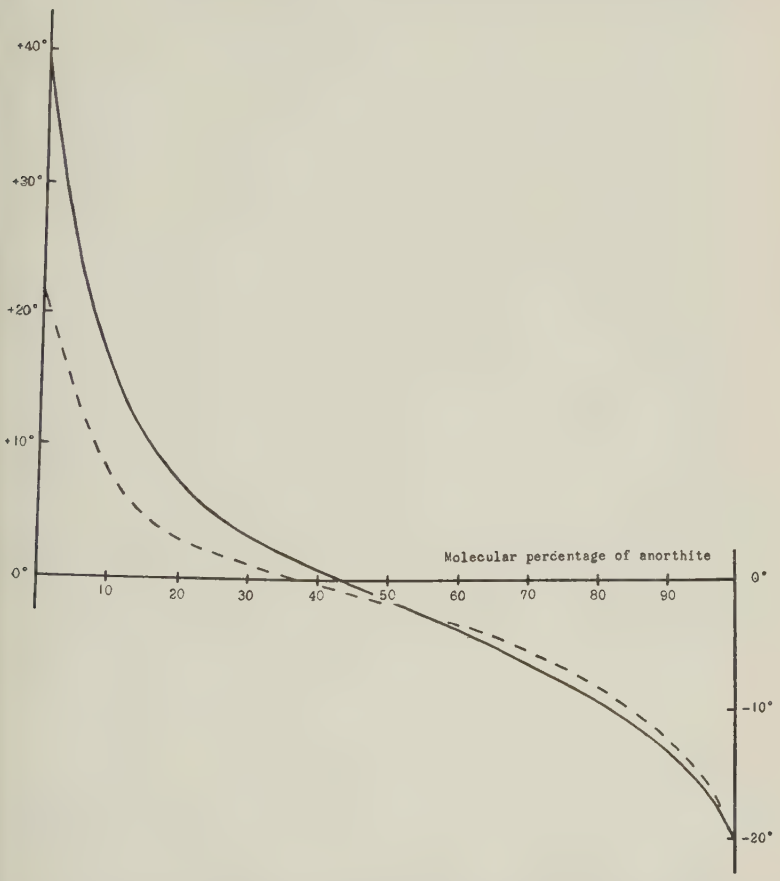


FIG. 1. Graph showing the variation of the angle $\sigma'$ with composition of plagioclase. The full curve is that due to Wülfing, the dotted curve that obtained from the Schuster-Becke values.

mined quantitatively, of other terms such as a potassic one in the albite-anorthite series.[1] Yet another factor is the possible presence of rarer twins which would yield an orientation practically coincident, though not exactly so, with that of the pericline law. If the true

[1] See also R. Sabot, Compt. Rend. Soc. Phys. Hist. Nat. Genève, 1918, vol. 35, pp. 72–76. [Min. Abstr., vol. 3, p. 515.]

character of these were not recognized, they would mark apparent divergences from the pericline migration curve. In particular, the complex ⊥ [100]/(001), as noted by Berek,[1] can scarcely be separated from the true pericline or acline-A twins. In Barth's values, the determination of $\sigma$ as 3° in a felspar containing 7% An presumably marks an acline-A twin. If the remaining thirteen values are referred to the Wülfing curve, in only three cases does the composition thus deduced differ by more than 5% An from that determined by extinction on (010). The average departure of the thirteen values is less than 2% An. It should be observed also that these measurements were carried out on material either associated with potash-microcline, or even forming one member of a microcline-microperthite.

In an attempt to obtain further data, I have prepared a series of sections of albite crystals (obtained from the collection in the Department of Mineralogy at Cambridge, by kind permission of Prof. A. Hutchinson) from the neighbourhood of the Ofenhorn and Wälschen Ofen in the Binn Valley, Switzerland.[2] The majority of the sections were cut approximately parallel to *a* (100), and eight showed twin traces parallel to the trace of the (001) cleavage. Measurement of these, however, showed that they were in every case acline-A twins. In some cases this could be verified directly, since the pole of the (001) cleavage could also be measured, and was found coincident with $P_{1-2}$,[3] or nearly so; in others it became evident on plotting in projection normal to [010].[4]

*Acline-A twins.*

| | | $n_\alpha$. | $n_\beta$. | $n_\gamma$. | |
|---|---|---|---|---|---|
| $T\text{-}A_{1-1'}$ | Average ... ... | +89° | +73½° | +16½° | (010) |
| | Variation (3 crystals) | ± ½ | ± 0 | ± ½ | |
| $T\text{-}A_{1-2}$ | Average ... ... | +88½ | +77 | +13 | [010] |
| | Variation (8 crystals) | ± 1 | ± 1 | ± ½ | |
| $P_{1-2}$ | Average ... ... | −74 | +20½ | −77 | (001) |
| | Variation (8 crystals) | ± 5 | ± 3½ | ± 1½ | |

(Where the positions of the optic axes A and B could be obtained, check values of the optic axial angle 2V, of the angles between the optic axes of different kinds, and of the angles between the optic axial planes were obtained, but it does not seem necessary to list all these in detail.)

[1] M. Berek, Mikroskopische Mineralbestimmung mit Hilfe der Universaldrehtischmethoden. Berlin, 1924, p. 82. [Min. Abstr., vol. 2, p. 365.]

[2] L. Desbuissons, La Vallée de Binn (Valais.). Lausanne, 1909, pp. 177–178. C. Hintze, Handbuch Min., 1905, vol. 2, p. 1460.

[3] For the nomenclature of poles of twin-planes and twin-axes, see W. Campbell Smith, Min. Mag., 1928, vol. 21, p. 544.

[4] L. Duparc and M. Reinhard, loc. cit., p. 116.

The average values for T-$A_{1-1}'$ and T-$A_{1-2}$ coincide almost exactly with the pure albite ends of the corresponding curves for (010) and [010], as plotted by Duparc and Reinhard (loc. cit., pl. 9), but that for $P_{1-2}$ falls a few degrees distant from (001). The larger values for the maximum variations in the case of this pole are of course due to the greater uncertainty of the practical measurements. A probable cause of the displacement of the average position, and indeed of much of the uncertainty of the whole of the question under discussion, is suggested by one section, of which a sketch is given in fig. 2. The lamellae 2 are bounded against 1 by two quite sharply defined sets of boundaries. The pole of one set, as determined under the microscope, obviously coincided with that of the (001) cleavage well displayed in 1, giving an angle $\sigma' = 0°$ and an obvious acline-A twin. The pole of the other set gave an angle $\sigma' = 12°$ only, and by itself would constitute an apparently anomalously low inclination of the 'rhombic section'.

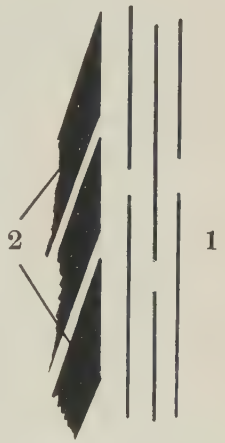


Fig. 2. Diagram showing the relationship of twin-lamellae (2) to the main portion of the crystal (1) in a measured acline-A twin.

Two instances of the true pericline twin in pure albite have been observed in porphyroblasts in chlorite-albite-epidote-schists ('Green Beds') from the Dalradian succession of Scotland, measurement of which gave:

*Pericline twins.*

| | | $n_{\alpha}$. | $n_{\beta}$. | $n_{\gamma}$. | |
|---|---|---|---|---|---|
| T-$A_{1-2}$ | Average (2 crystals) ... | +88° | +77° | +13½° | [010] |
| $P_{1-2}$ | Average (2 crystals) ... | +76 | +20 | −76½ | Rhombic section. |

Angle $\sigma' = 36°$.

It is perhaps worth noting that this association with stress conditions is not unnatural. Mügge[1] has pointed out that the rhombic section as composition-plane is to be expected if the twins are produced by simple gliding; but that the presence of isomorphous zoning would have as consequence a composition-plane curved around [010], and would therefore make difficult the mechanical

[1] H. Rosenbusch, Mikrosk. Physiogr. der petr. wicht. Min., 1927, vol. 1, pt. 2, p. 747, footnote 2.

production of such twins. Actually the pericline twin assumes a special importance in metamorphic schists and gneisses (where zoned felspars are rare, and stress is of the required kind) as observed by Becke, by Duparc and Reinhard (loc. cit., p. 9), and by myself. The well-formed albites of the Binn Valley occurrences are presumably growth-twins, and nothing is at present known of the factors determining twinning under these conditions.

In the light of this discussion, the following conclusions seem justifiable:

I. At the acid end of the series, as at the basic, there exists, in addition to the true pericline twin, a twin on the acline-A law.

II. In the true pericline twin, with variable composition-plane, the high values of $\sigma'$ suggested by theory are actually met with in practice, and the Wülfing curve is to be regarded as the true locus of the pole of this composition-plane.

III. Though the two kinds of twin can readily be separated in a special projection, or directly where the pole of the cleavage is also determined, no error of serious significance to the petrologist is likely to arise if the pole is arbitrarily referred to whichever of the migration-curves—that for (001) or that for the rhombic section—with which it more nearly coincides.

Department of Mineralogy,
Cambridge, June, 1929.

# *The occurrence of potassium nitrate near Goyder's Pass, McDonnell Ranges, Central Australia.*

By Sir Douglas Mawson, D.Sc., B.E., F.R.S.
Professor of Geology and Mineralogy in the University of Adelaide.

[Read January 14, 1930.]

ABOUT two years ago an aboriginal at Alice Springs in Central Australia reported that at a spot near the western extremity of the McDonnell Ranges the earth, if thrown upon a camp fire, did not extinguish the flames, but on the contrary increased the blaze. To those who heard the story this suggested the occurrence of oil, and it was decided to make some investigations. With the assistance of the native the spot was visited and located on the map. A sample of a white substance, which stimulated the burning of faggots, was forwarded to Adelaide University for examination and proved to be potassium nitrate. As a consequence Mr. C. T. Madigan, B.E., M.A., and myself paid a visit of inspection to the locality.

*Location.*—The discovery is situated about 120 miles due west of Alice Springs and a little to the south of Mt. Zeil. Its position is more definitely fixed on the map by stating that it lies some three or four miles to the north-east of Goyder's Pass. It is, therefore, in what is known as Mareenie Valley, located in undulating country with high ranges to the north and to the south.

The deposit of potassium nitrate is in the higher portion of a small hill rising about 70 feet above a dry gum-creek which extends along its western side, distant a quarter of a mile. This rise is one of several situated along the outcrop of a belt of dolomitic limestone, which latter trends in a nearly north and south direction.

The immediate vicinity is covered with porcupine grass, though the country thereabouts is principally occupied by mulga scrub. Timber of any size, such as *Eucalyptus rostrata,* appears only along the gum-creek and other dry watercourses of the neighbourhood. The latter carry surface water only during and immediately after

a fall of rain, a contingency which is of extremely infrequent occurrence. The average total annual precipitation amounts to only about 13 inches. However, a permanent pool of water exists at Old Glen Helen Station, located about six or seven miles to the north-east. The average annual evaporation in this area is believed to be in the neighbourhood of 10 feet.

*The Nature of the Occurrence.*—The nitrate occurs as disseminations beneath the hard surface crust of a prominence along the outcrop of the belt of dolomitic limestone, which is of Cambrian or pre-Cambrian age. To the south, distant only a couple of miles, is the wall-like upturned edges of the basal quartzites of the Larapintine Formation (Ordovician). This extends east and west. Five or six miles to the north is Mt. Zeil which, with other outstanding features of the northern flank of the McDonnell Ranges in the locality, are suggestive as representing portions of an overthrust or overfolded quartzite block probably of the same age as the foregoing.

The intervening area, wherein is the dolomite in question, is occupied by a rock formation which appears to be a twisted and deformed extension of that immense series of uniformly bedded, east and west trending, cryptozoon limestones, slates, and quartzites which extend regularly for 100 miles to the west of Alice Springs, underlying the Ordovician and overlying the crystalline pre-Cambrian.

For a distance of a mile and a half along the outcrop of the dolomitic limestone, occasional prominences are to be met with; the existence of each of these is due to local crustal hardening by silicification and ferruginization and the consequences of differential erosion. That where the nitrate deposit occurs is the most extensive of these. Apart from this particular one, indications of nitrate were observed in others of the prominences, but there appears to be no deposit of any importance connected with them.

The hard siliceous and ferruginous crusts are partly of a brecciated nature and appear to average only a few feet in thickness. That associated with the nitrate deposit is roughly 100 by 80 yards with an extension of another 30 yards as an offshoot in one direction. Over an area of about 50 by 30 yards towards the eastern side of the rise, the ground is cavernous below the hard crust, which is only a few feet in thickness. In places the crust has fractured and caved in.

The hard crust, more or less impervious to rain, appears to have originated by a superficial case-hardening process of silicification

and ferruginization. Such geological activities are frequently and widely evidenced in the arid interior of Australia. The brecciated nature of the crust rock is to be explained as a silicified residual breccia from the collapse of a cavernous area in the limestone belt. It would appear that here is the locus of a former long-existing cave area, now almost entirely obliterated by collapse and infilling of

FIG. 1. Entrance to cave under case-hardened crust. Nitrate deposit near Goyder's Pass, McDonnell Ranges, Central Australia.

cave earth. There are now only small, shallow caverns under the cappings, but in the past there may have been a more extensive system.

Small animals, such as lizards, snakes, bats, and wallabies, even now find shelter there. But there came under notice no present accumulation of guano beyond a small quantity of that black nitrogenous, pitch-like substance, so widely occurring in arid Australia and which is commonly and apparently rightly ascribed to bats.

On the eastern side of the rise a shallow cavern extends inwards below the crust for a few yards (fig. 1). The main evidence of the occurrence of nitrate is displayed in this. The latter substance appears as festoons on the wall and abundantly intercalated in the

rock itself (fig. 2). The latter is the rotten siliceous residue of the leached impure dolomitic limestone and is coloured and hardened by deposition of limonite. The saline matter with which it is saturated has assisted in the breaking down and recementation of the rock. The colour of the rock varies from a light ochreous character to a dark brown.

Fig. 2. View of the wall-face in the cave, showing the potassium nitrate as white impregnations through the rock.

The wall rock of the cave shows white encrustations and veining of nitrates. A picked sample of these white salts showed the presence of 99 % of nitrates of potassium and sodium, of which 95 % is potassium nitrate. An average sample of the wall rock taken towards the northern end of the face yielded on analysis 8·34 % of total soluble salts, of which 4·76 % was potassium nitrate. This sample was taken as a scaling over a height of 8 feet.

The richest face is on the south end of the cave wall. There the average value of a 4-foot vertical face is 22·14 % of soluble salts, of which 18·77 % is potassium nitrate.

The floor of the cave is occupied by detached blocks of the roof and wall rock embedded in a fine yellow ochreous powder. This latter, exposed in a winze which we sank 6 feet below the floor of the cave, was sampled and examined for potassium nitrate, but

returned only 0·72 % out of a total of 2·27 % of soluble salts. These figures are all the result of analyses by Mr. W. T. Chapman on samples carefully taken by C. T. Madigan and myself.

The potassium nitrate occurs for the most part either as saturations in the cave rock or as friable crystalline granular masses in pockets and veins in the wall rock. More rarely it appears as oriented,

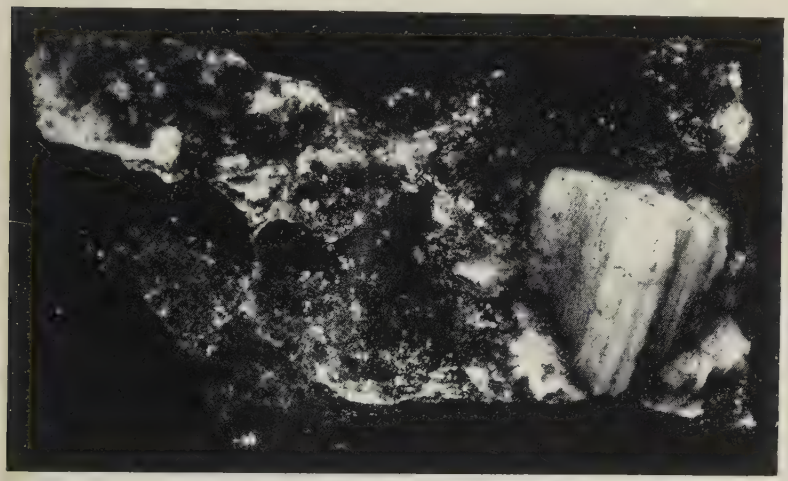

Fig. 3. A crystalline growth of potassium nitrate from a vugh.

crystalline growths from the wall of vughs. One of the best examples observed of these growths is shown in fig. 3.[1]

*The Origin of the Nitrate.*—There is nothing to suggest that the nitrate was originally a deposition contemporaneous with the sedimentation which developed the ancient dolomitic limestones. It appears to be an introduction of comparatively recent age in the geological sense. The most probable explanation is that in some manner it originated from the excreta of animals that, for ages past, had found a haven amongst these rocks and the collapsed cavernous formation there represented. The case-hardened surface sheds whatever rain falls upon it, so that below it there is no efficient downward leach whereby the belt above ground-water level would otherwise have been maintained comparatively free of such salts as nitrates.

The maintenance of soluble salts such as nitrates, therefore, owes

[1] The specimen figured has been presented to the British Museum collection of minerals.

much to the existence of an impervious case-hardened surface thereabouts. Small downward percolation of water, invading the ground below the crust along fracture lines would act as carriers for the nitrate impregnations; both assisting in its disseminations and in concentrating it elsewhere in vughs and fissures.

*Some other occurrences of Mineral Nitrates in Australia.*

Guano, principally derived from bats, is of common occurrence in caves in the ancient limestones of the Flinders Range of arid northern South Australia. Of these the caves north of Carrieton are famous for deposits of bat guano rich in salts of ammonia, which have arisen by bacterial changes in the guano, while it is maintained in a practically dry condition.

Farther north on Wooltana Station, near Mt. Warren Hastings, and about 85 miles east of Farina is another occurrence of a specially interesting nature. This cave is limited practically to one large, nearly vertical entrance descending from the summit of a prominent hill of pre-Cambrian limestone. Around the upper portion of the cave to a depth of quite 80 feet there is to be noted an abundance of the pitch-like bat guano in crevices and seams. The cavern descends almost vertically to a depth of about 300 feet, opening out below into a great and extensive vault, floored with a great depth of comminuted fragments of bat bones and other debris, with which are an abundance of almost pure ammonia compounds, principally sulphate and chloride.

A case corresponding in many respects with that of Goyder's Pass was described some years ago from a locality in South Australia in the 10-inch rainfall belt. There, at Elder Rock[1] near Paratoo, a case-hardened ferruginous breccia rises abruptly from the plain. Mineralized phosphatic residues, 'paratooite',[2] encrust the summit of the rock and ammoniacal salts, including ammonium nitrate, impregnate the underlying formation to a depth of quite 60 feet, as proved by mining operations. The ammoniacal salts were present to the extent of only 2 or 3 %. Analyses made at the time by the Mines Department indicated the presence of both ammonia and nitrate, and these constituents were recorded as ammonium nitrate.

[1] D. Mawson and W. T. Cooke, The phosphatic minerals of Elder Rock. Trans. Roy. Soc. S. Australia, 1907, vol. 31, p. 65.

[2] This material is very similar to corresponding phosphatic compounds recorded by A. Lacroix from several sources in other parts of the world.

In all these cases the fixed nitrogen can be sufficiently accounted for as a derivative of animal life attracted to the several localities by reason of the offer either of cave shelter or of the sanctuary and look-out afforded by a rocky hill top.

In the arid portions of Australia there is evidently a notable conservation of nitrogen in the soil. This has been noted[1] in the case of Western Australia by Dr. E. S. Simpson, the Government Mineralogist and Analyst. He states that 'Within an area bounded roughly by Lats. 24° and 30° S. and Longs. 116° and 124° E. the underground waters contain, in addition to the usual cyclic salts, an appreciable amount of a soluble nitrate'. Dr. Simpson found in these from a trace to 0·0362 %. The average of thirty-nine waters was 0·0111 % sodium nitrate, or nineteen parts of nitric nitrogen. He suggests that this is the result of active bacterial action in the soil. It is interesting that the region here referred to is notable for abundance of mulga scrub. Dr. Simpson points out that mulga is an acacia of the order leguminosae, considered to promote indirect fixation of nitrogen in the soil.

I am informed also that certain underground waters from the Tarcoola district, South Australia, examined by W. T. Chapman, Analyst to the Mines Department, have proved to contain notable quantities of nitrate nitrogen.

In seeking an explanation for this nitrate in the soil and groundwaters, there is also to be accounted the fact that the earth's surface the world over receives considerable contributions of nitrogen, fixed in the air by lightning discharge. It is estimated[2] that by this means 100,000,000 tons of nitrogen are fixed annually and carried to the earth's soil by rain, snow, and hail.

The leaching effect of abundant rainfall and the drain made by plants upon such soluble constituents of the soil does not ordinarily allow of the accumulation therein of nitrates. But in arid regions it may be that under special circumstances these constituents are accumulated in quite notable proportion. Hence, after useful falls of rain, the surprising fertility of Australia's arid lands.

[1] Bull. Geol. Survey W. Australia, 1916, no. 67, p. 143.

[2] Report on the fixation and utilization of nitrogen. War Dept. Pub.

# PUBLICATIONS

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